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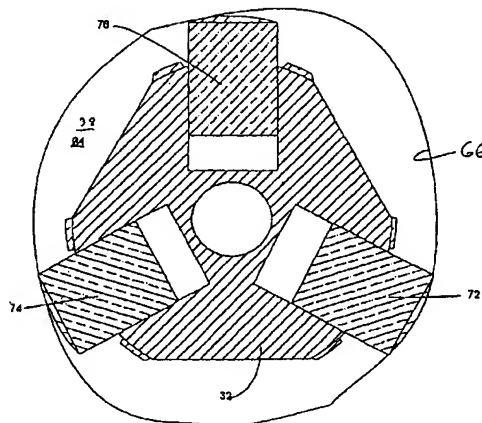
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(54) Title: METHOD AND APPARATUS FOR MWD FORMATION TESTING



(57) Abstract: A method and apparatus for formation testing is disclosed. In a preferred embodiment, a formation testing tool includes a longitudinal body with a flowbore; a plurality of extendable centralizing pistons (72, 74, 76) coupled to the body; an extendable sample device coupled to the body; and a centralizing hydraulic circuit configured to cause each of the plurality of centralizing pistons to extend at substantially the same rate. The centralizing hydraulic circuit includes a series of flow control and pressure-determining valves configured to extend the centralizing pistons at substantially the same rate, and to help maintain stability in the hydraulic circuit in response to external pressures. In some embodiments, the extendable sample device is preferably configured to be recessed beneath a surface of the body in a first position and to extend beyond the surface in a second position. The extendable sample device is preferably extended to contact the borehole wall substantially normal to the wall, protecting the sample device from excessive bending moments and other excessive forces.

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METHOD AND APPARATUS FOR MWD FORMATION TESTING

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

5 Not applicable.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates generally to a method and apparatus utilized in hydrocarbon exploration. More specifically, the invention relates to formation testing tools. Even more
10 particularly, the present invention is directed to methods and apparatus for performing formation testing while drilling.

Background and Related Art

Geologists and geophysicists are interested in the characteristics of the formations encountered by a drill bit as it is drilling a well for the ultimate production of hydrocarbons
15 from the earth. Such information is useful in determining the correctness of the geophysical data used to choose the drilling location and in choosing subsequent drilling locations. In horizontal drilling, such information can be useful in determining the location of the drill bit and the direction that drilling should follow.

Such information can be derived in a number of ways. For example, cuttings from the
20 mud returned from the drill bit location can be analyzed, or a core can be bored along the entire length of the borehole. Alternatively, the drill bit can be withdrawn from the borehole and a "wireline logging tool" can be lowered into the borehole to collect data or otherwise determine formation characteristics. In still another approach, called "measurement while drilling" ("MWD") or "logging while drilling" ("LWD"), tools are included in the drill string that collect
25 formation data while the drill bit remains in the borehole.

One type of formation testing tool measures formation pressure, which can be used for a variety of purposes, including computing the permeability and porosity of the formation. A conventional such formation testing tool operates in the wireline environment. It is lowered into the well to a depth where formation testing is desired. Before the wire line tool can be
30 lowered, however, the entire drill string must be removed from the borehole. This process, known as "tripping" is a laborious and time consuming process by which the drill string, which may be miles long, is removed from the hole, pipe section by pipe section. After the formation tester has been lowered to the appropriate depth by means of a wireline, the borehole interval adjacent to the tester must be packed off and isolated from the drilling fluid that remains in and

fills the borehole so that accurate reading of the formation pressure can be obtained. With the pressure recorded, the tool is retrieved to the surface for analysis and the drill string is then reassembled and replaced in the borehole, section by section. As well be understood, conducting formation tests via a wireline tool is time consuming and costly, given that costs of drilling a well may be thousands of dollars per hour.

As mentioned above, testing the formation using a tester incorporated into the drill string is desirable in that the drill string does not need to be removed to conduct the test. However, there are various complications associated with conventional such apparatus. For example, in certain such testers, the flow of drilling fluid must be stopped in order to measure the formation pressure or take a sample of the formation fluid. When this occurs, without the flow of constantly moving drilling fluid, the bottom hole assembly can become stuck in the hole, necessitating a costly and time consuming procedure to free the stock tool. Furthermore, mud turbine generators are sometimes employed in the bottom hole assembly as the means of supplying electrical power needed to actuate the formation tester. In such tools, stopping the flow of drilling fluid therefore prevents the tool from generating the needed electrical power, and power to operate the formation tester must be supplied by other means, such as batteries which, in certain instances, may be less reliable or otherwise less desirable. Other problems and shortcomings are associated with present day formation testers.

For example, certain conventional formation testers employ a extendible probe that extends from the tool to engage the borehole wall in order to conduct the fluid test or sampling. In certain instances, however, particularly when drilling a horizontal well, the orientation of the tool may be such that the probe extends out of the tool on the low side of the hole. When this occurs, the extending probe may be subjected to detrimental loading as the piston extends and contacts the borehole. Further, there are many instances during which the extending probe will engage the borehole wall at an angle, rather than being normal to the wall. When this occurs, the seal necessary for properly extracting and measuring formation fluid pressure is difficult, if not impossible, to achieve.

Accordingly, there remains a need in the art for a formation testing apparatus that may be employed in a drill string to conduct reliable formation testing. Ideally, such apparatus would not require that the flow of drilling fluid be cut off so as to prevent the bottom hole assembly from sticking to the borehole and permit the formation tester to be powered by the flow of drilling fluid. Further, it would be preferable if the sensed data and other measurements could be communicated to the surface via mud pulse telemetry, which relies on the flow of drilling fluid. A formation tester that insures that an extending probe contacts the borehole wall

substantially normal to the wall, rather than at an angle, and which protects the probe from excessive bending moments and other excessive forces would be particularly welcomed by the industry.

BRIEF SUMMARY OF SOME OF THE PREFERRED EMBODIMENTS OF THE INVENTION

In accordance with the spirit of the present invention, a novel formation testing tool is described herein. One property of the present formation testing tool is that an extending probe or sample device contacts the borehole wall substantially normal to the wall, protecting the probe from excessive bending moments and other excessive forces.

Several embodiments are disclosed as being illustrative of the spirit of the invention. For example, in one embodiment, the formation testing tool includes a longitudinal body with a flowbore; a plurality of extendable centralizing pistons coupled to the body; an extendable sample device coupled to the body; and a centralizing hydraulic circuit configured to cause each of the plurality of centralizing pistons to extend at substantially the same rate. The centralizing pistons are extended at substantially the same rate to assist in positioning the extending sample probe such that it is substantially normal to the borehole wall. The centralizing hydraulic circuit includes a series of flow control and pressure-determining valves configured to extend the centralizing pistons at substantially the same rate, and to help maintain stability in the hydraulic circuit in response to external pressures. The circuit also includes a controller for operating and managing the valves and pistons. The extendable sample device is preferably configured to be recessed beneath the surface of the body in a first position and to extend beyond the surface in a second position.

Methods of use for the formation testing tool are also described herein. For example, a method for formation testing comprising includes extending at substantially the same rate a plurality of centering pistons from a formation testing tool; centering the formation testing tool in a borehole; and testing the formation. These and other embodiments of the present invention, as well as their features and advantages, will become apparent with reference to the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed description of the preferred embodiments of the invention, reference will now be made to the accompanying drawings in which:

Figure 1 is a schematic view, partially in cross-section showing a well being drilled including a bottom hole assembly that includes a formation testing tool of the preferred embodiment;

Figure 2 is an elevation view, partially in cross-section of the formation testing tool of Figure 1;

Figure 3 is an elevation view of the formation testing tool of Figure 2;

Figures 4, 5, 6, 7 and 8 are cross sectional views along lines A-A shown in Figure 3 of the formation testing tool of Figure 3;

Figure 9A is a schematic of a hydraulic circuit of the centralizer pistons of the formation testing tool of Figure 3;

Figure 9B is a flow chart showing the preferred sequence of operation of the formation testing tool of Figure 3;

Figures 10 and 11 are cross sectional views along lines B-B shown in Figure 3 of the formation testing tool of Figure 3;

Figure 12 is a schematic of a hydraulic circuit of the seal piston and drawdown piston of the formation tester of Figure 3; and

Figure 13 is a flow chart showing the preferred sampling sequence for the formation tester of Figure 3.

NOTATION AND NOMENCLATURE

In the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus are to be interpreted to mean "including, but not limited to...". Reference to up or down will be made for purposes of description with "up," "upward," or "upper" meaning toward the surface of a well and "down," "downward," or "lower" meaning toward the bottom of a well. In addition, the term "couple," "couples," or "coupled" is intended to mean either an indirect or a direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection, or through an indirect electrical or fluid connection via other devices and connections.

This exemplary disclosure is provided with the understanding that it is to be considered an exemplification of the principles of the invention, and is not intended to limit the invention to that illustrated and described herein. In particular, various embodiments of the present invention provide a number of different constructions and methods of operation. It is to be fully recognized that the different teachings of the embodiments discussed below may be employed separately or in any suitable combination to produce desired results.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Figure 1, a drilling rig 10 (simplified to exclude items not important to this application) comprises a derrick 12, derrick floor 14, draw works 16, hook 18, swivel 20, kelly joint 22 and rotary table 24, such components being arranged in a conventional manner so as to

support and impart rotation to drillstring 26. Drill string 26 includes at its lower end a bottom hole assembly 29 which comprises drill collar 28, MWD tool 30 (which may be any kind of MWD tool, such as an acoustic logging tool), MWD formation testing tool 32 (which may be a separate tool as shown or may be incorporated into another tool) and drill bit 34. A description of exemplary MWD tools and MWD formation testing tools may be found in the provisional Patent Application Number 60/381,243 filed May 17, 2002, entitled Formation Tester, and in the patent application filed concurrently herewith via Express Mail No. EV324573681US and entitled MWD Formation Tester, which claims priority to the previously referenced provisional application, both applications hereby incorporated by reference herein for all purposes. Drilling fluid (which may also be referred to as "drilling mud") is injected into the swivel by a mud supply line 36. The mud travels through the kelly joint 22, drillstring 26, drill collars 28, MWD tool 30 and MWD formation testing tool 32 and exits through ports in the drill bit 34. The mud then flows up the borehole 38. A mud return line 40 returns mud from the borehole 38 and circulates it to a mud pit (not shown) and ultimately back to the mud supply line 36.

The data collected by the MWD tool 30 and formation testing tool 32 is returned to the surface for analysis by telemetry transmitted in any conventional manner, including but not limited to mud pulse telemetry, or EM or acoustic telemetry. For purposes of the present application, the embodiment described herein will be explained with respect to use of mud pulse telemetry. A telemetry transmitter 42 located in a drill collar 28 or in one of the MWD tools collects data from the MWD tools and transmits it through the mud via pressure pulses generated in the drilling mud. A telemetry sensor 44 on the surface detects the telemetry and returns it to a demodulator 46. The demodulator 46 demodulates the data and provides it to computing equipment 48 where the data is analyzed to extract useful geological information.

Further, commands may be passed downhole to the MWD tool and formation testing tool 32 in a variety of ways. In addition to the methods described in the previous paragraph, information may be transmitted by performing predefined sequences of drill pipe rotations that can be sensed in the MWD tools and translated into commands. Similarly, the mud pumps may be cycled on and off in predefined sequences to transmit information in a similar fashion.

The formation testing tool 32 includes a plurality of centralizing pistons 60 and one or more sampling pistons 62, as shown in Figure 2. For present purposes, the formation testing tool will be described with reference to tool 32 having one sampling piston 62, it being understood that the tool could likewise be configured to include additional such pistons 62. The plurality of centralizing pistons 60 centralize the formation testing tool 32 in the borehole 38. Once the formation testing tool 32 is centralized, the sampling piston 62 extends from the

formation testing tool 32 to the borehole wall 66, where it seals against the wall and allows formation testing to be performed.

In one embodiment of the formation testing tool 32, the centralizing pistons 60 are all in the same cross section and the sampling piston 62 is in a different cross section. In another
5 embodiment, one or more of the centralizing pistons 68 are in a different cross-section from the remaining centralizing pistons 60. In still another embodiment, the centralizing pistons are in three or more cross sections.

During drilling operations, the centralizing pistons 60 and the sampling piston 62 are retained in a retracted position inside the formation testing tool 32, as shown in Figure 3. In
10 this position, the sampling piston 62 is recessed below the surface of the formation testing tool 32, as is discussed further below. When it is time to perform the formation testing function, the rotation of the drill string 26 is ceased and the centralizing pistons 60 are extended at the same rate so that the formation testing tool 32 is relatively centralized within the borehole, as shown in Figure 2. The sampling piston 62 is then extended and the formation testing tool 32
15 performs its testing function.

The formation testing tool 32 is centralized before the sampling piston 62 is extended for several reasons. Centering the formation testing tool 32 in the borehole improves the likelihood that the sampling piston 62 will only have to be partially extended to reach the borehole wall 66. The sampling piston 62 is less vulnerable to bending when it is partially
20 extended than when it is fully extended. This is especially important in MWD applications in which torque or axial loads may be inadvertently applied to tool 32. Further, centering the formation testing tool 32 increases the likelihood that the sampling piston will be normal to the borehole wall rather than at an angle, which improves the conditions for sealing the piston against the borehole wall. Still further, centralizing the tool 32 in the borehole maximizes the
25 size of the borehole that can be sampled with a given centralizing piston length. The short distance that the centralizing pistons 60 need to be extended allows more room in the drill collar for fluid flow through the flowbore of the tool. Preferably, the tool 32 will operate while drilling fluids remain circulating in borehole 38 which will minimize the possibility of the tool assembly sticking, allow data to be transmitted to the surface for real-time examination and
30 decision making, and allow the centralizing and sampling pistons to be powered by a mud turbine generator which require the continuous flow of drilling fluid to operate.

The formation testing tool's 32 centering apparatus is illustrated in Figure 4. In the embodiment illustrated in Figure 4, the formation testing tool 32 includes three centralizing pistons 72, 74 and 76. It will be understood that tool 32 can include any number of centralizing

pistons that accomplish the functions described below. A flowbore 78 through the center of the formation testing tool 32 allows drilling mud to flow through the tool to the drill bit 34 at the end of the drill string 26 (Figure 1). Flowbore 78 is preferably centralized in formation testing tool 32 but may be offset from the axis of the tool 32. Hardfacing 80 is coupled to portions of
5 the tool 32 to prevent damage to the tool during drilling operations.

Figure 5 shows the formation testing tool 32 in the borehole 38 after the drill string has stopped rotating. An annulus 92 is formed between tool 32 and the borehole wall 66. As can be seen in Figure 5, the formation testing tool 32 has stopped in a position in which it is not aligned with the center of the borehole. Centralizing piston 72 is close to the borehole wall 66,
10 while the other pistons 74 and 76 are some distance away from the wall.

The centralizing process begins as shown in Figure 6. The three centralizing pistons 72, 74 and 76 begin to extend from the formation testing tool 32. The centralizing pistons 72, 74 and 76 extend at the same rate. The rate of extension may vary from moment to moment but the rate of extension for one piston at a given moment in time is substantially, *i.e.*, within that
15 allowed by tolerances, the same as the rate of extension of the other two pistons. Consequently, the three pistons 72, 74 and 76 will extend the same amount from the formation testing tool 32 at any given moment in time. Given its position relative to borehole wall 66, piston 72 pushes the formation testing tool 32 away from the borehole wall 66. The other pistons 74 and 76 have not yet contacted the borehole wall and, therefore, have no effect.

20 The centralizing process continues, as shown in Figure 7, with the centralizing pistons 72, 74 and 76 continuing to extend, all at the same rate. As shown in Figure 7, piston 72 has pushed the formation testing tool 32 far enough that piston 74 has come into contact with the borehole wall. Piston 76 has not yet contacted the borehole wall.

The final position is illustrated in Figure 8. All of the centralizing pistons 72, 74 and 76
25 are in contact with the borehole wall and, because they extended at the same rate, they extend the same distance from the formation testing tool 32. Consequently, the formation testing tool 32 is centered in the borehole.

The hydraulic circuit that accomplishes the centering function is schematically illustrated in Figure 9A. A controller 82 is connected to all of the controllable elements in the
30 hydraulic circuit illustrated in Figure 9A and in hydraulic circuits described below. The connections to the controllable elements are conventional and are not illustrated. Controller 82 is located in MWD tool 30, or in formation testing tool 32, or elsewhere in bottom hole assembly 29 (Figure 1). The sequence of operations coordinated by the controller 82 is illustrated in Figure 9B.

The controller 82 detects control signals, transmitted from the surface in one of the formats described above, ordering the formation testing tool 32 to conduct a formation test (block 138 in Figure 9B). When it receives the command, the centralizing pistons 60 and the sampling piston 62 are in their withdrawn positions, as shown in Figure 3. The drillstring has
5 stopped rotating.

The controller 82 orders the motor 84 to begin to rotate (block 140 in Figure 9B). The motor 84 can be an electric motor or a mud turbine or any other source of energy. The motor 84 is coupled to a pump 86 and causes pump 86 to draw hydraulic fluid out of a hydraulic reservoir 88 through a serviceable filter 90. The pressure of hydraulic reservoir 88 is
10 approximately equal to the pressure in the annulus 92 between the tool 32 and the wall of the borehole through the use of a pressure balance piston 250 (shown in Figures 9A and 12).

The pump 86 directs the hydraulic fluid into hydraulic circuit 100 that includes extend solenoid actuated valve 94, retract solenoid actuated valve 96, relief valve 98 and differential pressure transducer 99. The relief valve 98 prevents damage to the hydraulic circuit 100 and
15 provides other functions as described below. The electrical output of pressure transducer 99 is coupled to the controller 82 and allows the controller 82 to monitor pressure in hydraulic circuit 100 and control the progress of the formation testing operation, as described below.

The controller 82 actuates (or "opens") the extend solenoid actuated valve 94 (block 142 in Figure 9B). Prior to being actuated, in its "normal" position, valve 94 has its control
20 port (C) connected to its tank port (T), the position shown in Figure 9A. Upon actuation by controller 82, its control port (C) connects to its pump port (P). In this position, hydraulic fluid flows from the pump 86 to three pressure compensated flow control valves (FCVs) 102, 104 and 106. Each FCV has the characteristic that, when the pressure on its output side is between a minimum value and a maximum value (e.g., between 200 and 3000 p.s.i.), fluid flows from
25 its output side at a constant rate. Thus, for the range of operation between 200 and 3000 p.s.i., then the flow rate from the FCVs will be the same when the pressure on their output sides is, for example, 250 p.s.i. as it will when the pressure is, for example, 2550 p.s.i.

The hydraulic fluid flows through the FCVs 102, 104 and 106 to pilot control valves (PCVs) 108, 110 and 112, respectively. The PCVs 108, 110 and 112 act as check valves to
30 prevent the reverse flow of hydraulic fluid until the pressure applied to their pilot ports (shown on Figure 9A as dotted lines 114, 116 and 118) exceeds a predetermined amount, at which time they allow fluid flow in either direction.

The hydraulic fluid flows through the PCVs 108, 110 and 112 to relief valves 120, 122 and 124 and to the extend sides of centralizer pistons 72, 74 and 76, respectively. Centralizer

pistons 72, 74 and 76 are identified to pistons 60 previously described. The relief valves open at a predetermined pressure (for example 5000 p.s.i., as shown in Figure 9A), providing a safety function. The centralizer pistons 72, 74 and 76 attempt to move under the pressure exerted by the hydraulic fluid on their extend sides shown as 72e, 74e, 76e, respectively.

5 The retract side of the centralizer pistons 72, 74 and 76 (72r, 74r and 76r) are connected together, as shown at point 130 in Figure 9A, and are connected through a parallel-connected relief valve 132 and check valve 134 to the retract solenoid actuated valve 96, which has been left in its normally-closed position with the common (C) connected to the tank (T). The check valve 134 prevents the hydraulic fluid from flowing from the retract sides of the centralizer
10 pistons 72, 74 and 76 through its branch of the parallel hydraulic circuit. The relief valve 132 is sized to prevent hydraulic fluid from flowing from the retract side of the centralizer pistons 72, 74 and 76 until the pressure impinging on the relief valve 132 is within the operating range of the FCVs 102, 104 and 106. For the example shown in Figure 9A, the relief valve 132 is sized to open at 200 p.s.i., which is within the operating zone of the FCVs 102, 104 and 106.

15 Since the relief valve 132 opens at a pressure within the operating range of the FCVs 102, 104 and 106, fluid from each of the FCVs will flow at the same rate to the extend side of the centralizer pistons 72, 74 and 76, respectively. Consequently, the three centralizer pistons will begin to extend at the same rate. Even when one or two of the pistons encounter resistance, such as when one or two of the pistons press against the borehole wall as shown in
20 Figures 6 and 7, all three pistons will continue to extend at the same rate.

When all three centralizer pistons 72, 74 and 76 meet resistance, or when all three are fully extended, the pressure in the hydraulic circuit 100 will begin to climb. When it reaches a predetermined value, for example, 3000 p.s.i. as shown in Figure 9A, relief valve 98 will open and the pressure in the hydraulic circuit 100 will stabilize.

25 The controller 82, which has been monitoring the pressure in the hydraulic circuit through transducer 99 (block 144 in Figure 9B), detects the pressure stabilization caused by the opening of the relief valve 98. The extend solenoid actuated valve 94 remains energized so that if the tool 32 shifts, hydraulic pressure will be available to adjust the positions of the centralizer pistons 72, 74 and 76 to account for the shift and to "recentralize" the tool.

30 Now that the centralizer pistons 72, 74 and 76 are extended, the formation testing tool 32 is ready to begin its sampling operations. The sampling piston 62, illustrated in Figure 10, includes a seal piston 166 and a draw down chamber 168 inside and axially aligned with the seal piston 166. When the seal piston 166 and draw down chamber 168 are retracted into the tool 32, as shown in Figure 10, they are recessed below the surface of the tool 32. In particular,

the top of the seal piston 166 is beneath a straight line 170 connecting the low points 172 and 174 in the opening in the collar 176 provided for the sampling piston.

To perform the formation testing operation, the seal piston 166 is first extended to seal against the borehole wall 66, as shown in Figure 11. The centralizer pistons 72, 74 and 76 keep the formation testing tool 32 stable during this step which reduces the possibility of damage to the seal piston 166 as it is being extended. The draw down chamber 168 extends slightly into the mudcake formed on the borehole wall 66, thereby improving the seal between the tool and the wall of the 66 borehole 38. The purpose of the seal piston 166 is to seal against the borehole wall 66 so that the draw down chamber 168 can determine the pressure in the formation without being influenced by the pressure in the annulus 92 (such as drilling mud). The seal piston 166 and draw down chamber 168 are preferably separate from the centralizing pistons 72, 74 and 76 because the centralizing pistons 72, 74 and 76 may slip along the borehole wall 66 during centralizing. Such slipping might damage the seal piston 166 and prevent it from operating as required.

Once the seal piston 166 has extended, as shown in Figure 11, the draw down chamber 168 is activated to withdraw fluids from the formation. In one embodiment, the withdrawn fluids are stored within the tool 32. After the fluid sample has been withdrawn from the formation and the formation fluid pressure has been measured, the seal piston 166 and draw down chamber 168 are then withdrawn back into the tool 32.

The hydraulic circuit 101 used to control the seal piston 166 and the draw down chamber 168 is illustrated in Figure 12. The motor 84, pump 86, reservoir 88, filter 90, relief valve 98 and transducer 99 perform the same functions as the items bearing the same reference numbers in Figure 9A. Preferably, the two hydraulic circuits 100, 101 are independent and employ separate motors, pumps, hydraulic reservoirs, filter, relief valve and pressure transducer. Alternatively, they may be combined to share the same such components.

The controller 82 actuates seal piston extend solenoid actuated valve 180 causing its control port (C) to be connected to its pump port (P) (block 146 in Figure 9B). Hydraulic fluid flows through the seal piston extend solenoid actuated valve 180 and through check valve 182 to the extend side 166e of the seal piston 166 causing it to extend. When the seal piston 166 has extended to the point where it is sealed against the formation wall 66 (or it is fully extended) and it is no longer moving, the pressure within the hydraulic circuit 101 begins to increase. When the pressure reaches, for example, 3000 p.s.i., the relief valve 98 opens and releases hydraulic fluid from the hydraulic circuit into the reservoir 88. The check valve 182 prevents hydraulic fluid from draining from the seal piston 166 and keeps it sealed against the

borehole wall. When the controller 82, through pressure transducer 99, detects the pressure in the hydraulic circuit stabilizing because of the opening of the relief valve 98 (block 148 in Figure 9B), controller 82 activates the draw down chamber 168. The controller 82, which has been monitoring the pressure in the hydraulic circuit, does not deactivate the seal piston extend solenoid actuated valve 180 because if, for example, the tool 32 shifts so that the seal piston requires more hydraulic fluid to remain sealed against the borehole wall, the hydraulic fluid is available through seal piston extend solenoid actuated valve 180.

To activate the draw down chamber 168, the controller 82 activates a draw down chamber retract solenoid controlled valve 184, causing its control port (C) to be connected to its pump port (P) (block 150 in Figure 9B). Hydraulic fluid flows through the draw down chamber retract solenoid controlled valve 184 and into the retract side 168r of the draw down chamber 168, causing the draw down chamber to retract. As a draw down chamber piston 188 within the draw down chamber 168 retracts, a pressure transducer 190 measures the pressure in the formation fluid. The pressure transducer 190 sends the pressure data to the controller 82 which sends it to the surface for analysis and/or records it. The controller 82 may also analyze the data collected and record the results and/or send the results to the surface.

The draw down chamber piston 188 stops moving when it has fully withdrawn and pressure within the hydraulic circuit 101 begins to increase. When the pressure reaches 3000 p.s.i., relief valve 98 opens and releases hydraulic fluid from the hydraulic circuit 101 into the reservoir 88. When the controller 82, which has been monitoring the pressure in the hydraulic circuit through transducer 99 (block 152 in Figure 9B), detects a stabilization of the pressure in the hydraulic circuit 101, it deactivates the draw down chamber retract solenoid controlled valve 184 (block 154 in Figure 9B).

At the same time, the controller 82 activates a draw down chamber extend solenoid controlled valve 186, causing its control port (C) to be connected to its pump port (P) (block 154 in Figure 9B). Hydraulic fluid flows through the draw down chamber extend solenoid controlled valve 186 and into the extend side 168e of the draw down chamber 168, causing the piston 188 in the draw down chamber to extend. As the draw down chamber piston 188 within the draw down chamber 168 extends, it drives the formation fluid from the draw down chamber 168 through the central passageway of the seal piston 166 and into the annulus. Alternatively, the fluid may be driven into storage receptacles (not shown) for later analysis on the surface. The additional valves required to implement such a storage system are conventional and are not illustrated in Figure 12.

The draw down chamber piston 188 stops moving when it has fully extended and pressure within the hydraulic circuit 101 begins to increase. When the pressure reaches, for example, 3000 p.s.i., relief valve 98 opens and releases hydraulic fluid from the hydraulic circuit 101 into the reservoir 88. When the controller 82, which has been monitoring pressure through transducer 99 (block 156 in Figure 9B), detects a stabilization of pressure in the hydraulic circuit 101, it activates the seal piston retract solenoid controlled valve 187 and closes the seal piston extend solenoid controlled valve 180 (block 158 in Figure 9B). Hydraulic fluid flows through the seal piston retract solenoid controlled valve 187 and into the retract side 166r of the seal piston 166. The seal piston 166 is prevented from moving by the presence of the check valve 182, which prevents hydraulic fluid from flowing out of the extend side 166e of the seal piston 166. When the pressure on the retract side 166r of the seal piston reaches a predetermined level, the pilot port of the check valve 182 causes it to open which allows the seal piston 166 to move. When the seal piston has fully retracted, the pressure in the hydraulic circuit 101 increases until the relief valve 98 actuates. The pressure in the hydraulic circuit 101 then stabilizes.

Referring again to Figure 9A, the controller 82, which has been monitoring the pressure in the hydraulic circuit (block 159 in Figure 9B), actuates the retract solenoid actuated valve 96, which causes its control port (C) to be connected to its pump port (P) (block 160 in Figure 9B). At the same time, the controller deactivates the extend solenoid actuated valve 94 (block 160 in Figure 9B). Hydraulic fluid flows through the retract solenoid actuated valve 96, through check valve 134 and to the retract side of the centralizer pistons 72, 74 and 76. At first, the centralizer pistons 72, 74 and 76 cannot move because the PCVs 108, 110 and 112 prevent hydraulic fluid from flowing out of the extend side of the centralizer pistons 72, 74 and 76. Consequently, the pressure on the retract side of the centralizer pistons 72, 74 and 76 increases. At a predetermined pressure, the pilot ports 114, 116 and 118 of the PCVs 108, 110 and 112, respectively, cause the PCVs to open and allow hydraulic fluid to flow out of the extend side of the centralizer pistons 72, 74 and 76, through the FCVs 102, 104 and 106, respectively, through the extend solenoid actuated valve 94 and into the hydraulic reservoir 88. Consequently, the centralizer pistons 72, 74 and 76 will begin to retract.

When the centralizer pistons 72, 74 and 76 have fully retracted, the pressure in the hydraulic circuit 100 will begin to increase, and when it reaches, for example, 3000 p.s.i., the relief valve 98 will open causing the pressure to stabilize. The controller 82, which has been monitoring pressure in the hydraulic circuit through the transducer 99 (block 162 in Figure 9B), will detect that the pressure has stabilized and will turn the motor 84 off and return all valves to

their original conditions (block 164 in Figure 9B). The tool 32 is now back in its original condition.

The hydraulic circuit 100 illustrated in Figure 9A also includes a fail-safe feature. The control port of a fail-safe solenoid actuated valve 136 is connected to the extend side of the centralizer pistons 72, 74 and 76. In its normal, unactuated position, the control port (C) is connected to its tank port (T). When it is time to extend the centralizer pistons 72, 74 and 76, the controller 82 actuates the fail-safe solenoid actuated valve 136, which causes its control port (C) to become connected to its pump port (P). The pump port (P) is capped off, which prevents fluid from flowing through the fail-safe solenoid actuated valve 136. Should power fail, however, the fail-safe solenoid actuated valve 136 will deactivate and revert to the position shown in Figure 9A, which allows hydraulic fluid to flow from the centralizer pistons 72, 74 and 76 to the hydraulic reservoir 88 and allows the centralizer pistons 72, 74 and 76 to be pushed back into their retracted positions by forces outside the tool 32. Thus, if power to the tool 32 fails, the centralizer pistons 72, 74 and 76 will not be locked in their extended positions, where they would be susceptible to being damaged or destroyed if the drill string begins moving.

Operation of the MWD formation testing tool 32 after it is centralized in the borehole is illustrated in Figure 13. The process begins (block 192) by drawing a 10 cc sample from the formation (block 194) via seal piston 166. It will be understood that the size of the sample can vary. The controller 82 stores a draw down pressure profile as the sample is being taken. The sample pressure is compared to the annulus pressure (block 196). If the sample pressure is the same as the annulus pressure, then the test is considered to have failed. After the first failure, the sample is ejected into the annulus (block 198) and the process begins again (block 194). On the second and third failures, the sample is ejected to the annulus (block 200) and the seal piston is reset with an increased load (block 202), in the hope that increased pressure on the seal piston will seal it against the borehole wall. If the test fails a fourth time, the tool 32 transmits a "failed seal response" message to the surface (block 204). The process then ends (block 206).

If any of the comparisons of sample pressure to annulus pressure pass, the resistance of the sample is checked (block 208). A resistance test is a conventional test performed on formation fluids. If the formation fluid is conductive, it may be water, salt water, drilling mud, formation fluid contaminated with drilling mud, or some other conductive fluid. If the formation is resistive, it may be a hydrocarbon.

Alternatively, any other fluid test can be performed such as an NMR, salinity test, or infrared analysis. Regardless of the particular test performed, if the sample fails the test based

upon a predetermined test criteria, the fluid is ejected to the annulus 198 and the process is repeated (beginning at block 194). If the sample passes the resistance test (or other test that may be employed instead of or in addition to the resistance test), the controller 82 transmits the stored draw down pressure profile to the surface (block 210). The sample is then ejected into
5 the annulus. Alternatively, the sample is transferred to storage (block 212) for analysis at a time after tool 32 has been retrieved to the surface. Alternatively, the tool 32 may incorporate equipment to analyze the sample and transmit the results to the surface. The process then ends (block 214).

The above discussion is meant to be illustrative of the principles and various
10 embodiments of the present invention. While the preferred embodiment of the invention and its method of use have been shown and described, modifications thereof can be made by one skilled in the art without departing from the spirit and teachings of the invention. The embodiments described herein are exemplary only, and are not limiting. Many variations and modifications of the invention and apparatus and methods disclosed herein are possible and are
15 within the scope of the invention. Accordingly, the scope of protection is not limited by the description set out above, but is only limited by the claims which follow, that scope including all equivalents of the subject matter of the claims.

CLAIMS

What is claimed is:

1. A formation testing tool comprising:

a longitudinal body having a flowbore;

- 5 a plurality of extendable centralizing pistons coupled to the body;

an extendable sample device coupled to the body; and

a centralizing hydraulic circuit configured to cause each of the plurality of centralizing pistons to extend at substantially the same rate.

2. The formation testing tool of claim 1 further comprising a plurality of extendable
10 sample devices coupled to the body.

3. The formation testing tool of claim 1 wherein all of the plurality of extendable centralizing pistons are located at the same cross-section of the body.

4. The formation testing tool of claim 1 wherein at least one of the plurality of extendable centralizing pistons is located at a different cross-section than the remaining extendable
15 centralizing piston or pistons.

5. The formation testing tool of claim 1 further comprising:

a sample device hydraulic circuit configured to cause the sample device to extend; and

- a controller for controlling the centralizing hydraulic circuit and the sample
20 device hydraulic circuit.

6. The formation testing tool of claim 5 further comprising a pressure transducer coupled with the controller, the centralizing hydraulic circuit, and the sample device hydraulic circuit.

7. A formation testing tool comprising:

a longitudinal body having a surface;

- 25 an extendable sample device coupled to the body, the extendable sample device configured to be recessed beneath the surface of the body in a first position and to extend beyond the surface in a second position.

8. A formation testing tool comprising:

a longitudinal body;

- 30 an extendable sample device coupled to the body; and

a plurality of extendable centralizing pistons coupled to the body, the extendable centralizing pistons being configured to extend at substantially the same rate.

9. The formation testing tool of claim 8 wherein the plurality of extendable centralizing pistons are received in cylinders in the body, each cylinder having an extend side and a retract

side of its corresponding cylinder, the formation testing tool further comprising:

a source of hydraulic fluid;

5 a plurality of flow control valves, each flow control valve configured to communicate hydraulic fluid from the source to the extend side of a corresponding cylinder, each flow control valve communicating hydraulic fluid at substantially the same rate.

10. The formation testing tool of claim 9 further comprising:

10 a first pressure-determining valve in fluid communication with the retract side of the cylinders, the valve preventing the centralizing pistons from moving until the pressure on the retract side of the cylinders reaches a predetermined pressure.

11. The formation testing tool of claim 10 wherein the first pressure-determining valve is a relief valve configured to actuate at the predetermined pressure, the actuation of the relief valve allowing hydraulic fluid to flow from the retract side of the cylinders.

12. The formation testing tool of claim 10 wherein the first pressure-determining valve
15 comprises a solenoid activated valve.

13. The formation testing tool of claim 10 further comprising:

20 a second pressure-determining valve coupled between the hydraulic fluid source and the plurality of flow control valves, the second pressure-determining valve configured to communicate hydraulic fluid from the source to add the pressure to extend the plurality of centralizing pistons.

14. The formation testing tool of claim 13 wherein the second pressure-determining valve comprises a solenoid activated valve.

15. The formation testing tool of claim 10 further comprising a pilot control valve coupled between one of the plurality of flow control valves and the extend side of its corresponding
25 cylinder, the pilot control valve configured to prevent the flow of hydraulic fluid out of the extend side of the cylinder unless the pressure on the retract side of the cylinder exceeds the predetermined pressure.

16. The formation testing tool of claim 10 further comprising a fail-safe valve coupled to the extend side of the cylinders, the fail-safe valve configured to remove the pressure to extend
30 the plurality of centralizing pistons when power is removed from the fail-safe valve.

17. The formation testing tool of claim 16 wherein the fail-safe valve comprises a powered valve which in its unpowered condition communicates hydraulic fluid from the extend side of the cylinders to a hydraulic reservoir.

18. The formation testing tool of claim 17 wherein the powered valve comprises a solenoid

activated valve.

19. The formation testing tool of claim 9 wherein each flow control valve has an inlet side and an outlet side and allows fluid to flow from the inlet side to the outlet side when the pressure on the outlet side is between a lower limit pressure and an upper limit pressure.

5 20. The formation testing tool of claim 19 wherein the lower limit pressure is 200 p.s.i. and the upper limit pressure is 3,000 p.s.i.

21. The formation testing tool of claim 8 wherein the extendable sample device is received in a sample device cylinder in the body, the sample device cylinder having an extend side and a retract side of its corresponding cylinder, the formation testing tool further comprising:

10 a source of hydraulic fluid;

a sample device extend valve, the sample device extend valve configured to communicate hydraulic fluid from the source to the extend side of the sample device cylinder; and

15 a draw down chamber communicating with the hydraulic fluid source, the draw down chamber configured to actuate when the extend side of the sample device cylinder reaches a predetermined pressure.

22. The formation testing tool of claim 21 wherein the draw down chamber is received in a draw down cylinder in the body, the draw down chamber cylinder having an extend side and a retract side of its corresponding cylinder, the formation testing tool further comprising:

20 a sample device retract valve, the sample device retract valve configured to communicate hydraulic fluid from the source to the retract side of the sample device cylinder;

25 a draw down chamber extend valve, the draw down chamber extend valve configured to communicate hydraulic fluid from the source to the extend side of the draw down cylinder;

a draw down chamber retract valve, the draw down chamber retract valve configured to communicate hydraulic fluid from the source to the retract side of the draw down cylinder;

a hydraulic fluid pressure transducer; and

30 a formation fluid pressure transducer coupled between the draw down chamber and the extendable sample device.

23. A method for formation testing comprising:

extending at substantially the same rate a plurality of centering pistons from a formation testing tool;

centering the formation testing tool in a borehole; and
testing the formation.

24. The method of claim 23 wherein the testing step comprises extending a testing piston, separate from the plurality of centering pistons.

5 25. The method of claim 23 wherein extending a plurality of centering pistons comprises:
receiving a command from a controller;
starting a motor in response to receiving the command;
opening a centering piston extend valve; and
communicating from a hydraulic fluid source hydraulic fluid to each of the
10 plurality of centering pistons to cause each of the centering pistons to extend at substantially the same rate.

26. The method of claim 24 wherein extending a testing piston comprises:
opening a testing piston extend valve;
communicating from a hydraulic fluid source hydraulic fluid to the testing
15 piston;
exerting a hydraulic fluid pressure on the testing piston; and
stabilizing the fluid pressure.

27. The method of claim 26 wherein testing further comprises:
opening a draw down chamber retract valve;
20 communicating hydraulic fluid from the hydraulic source to the draw down chamber;
exerting a hydraulic fluid pressure on the draw down chamber;
communicating a formation fluid sample from the testing piston to the draw down chamber; and
25 comparing the formation fluid sample pressure to an annulus fluid pressure.

28. The method of claim 27 wherein testing further includes ejecting the formation fluid sample from the drawdown chamber and from the testing piston if the formation fluid sample pressure and the annulus fluid pressure are substantially the same.

29. The method of claim 27 wherein testing further includes performing a fluid test on the
30 formation fluid sample.

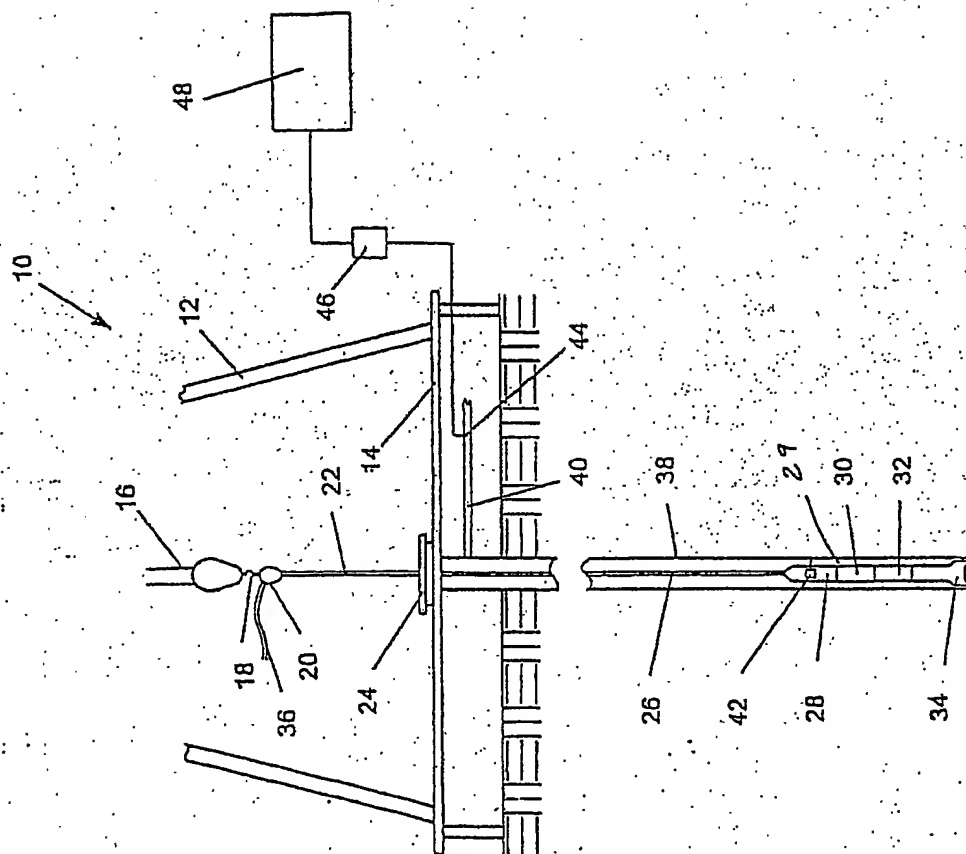


Fig. 1

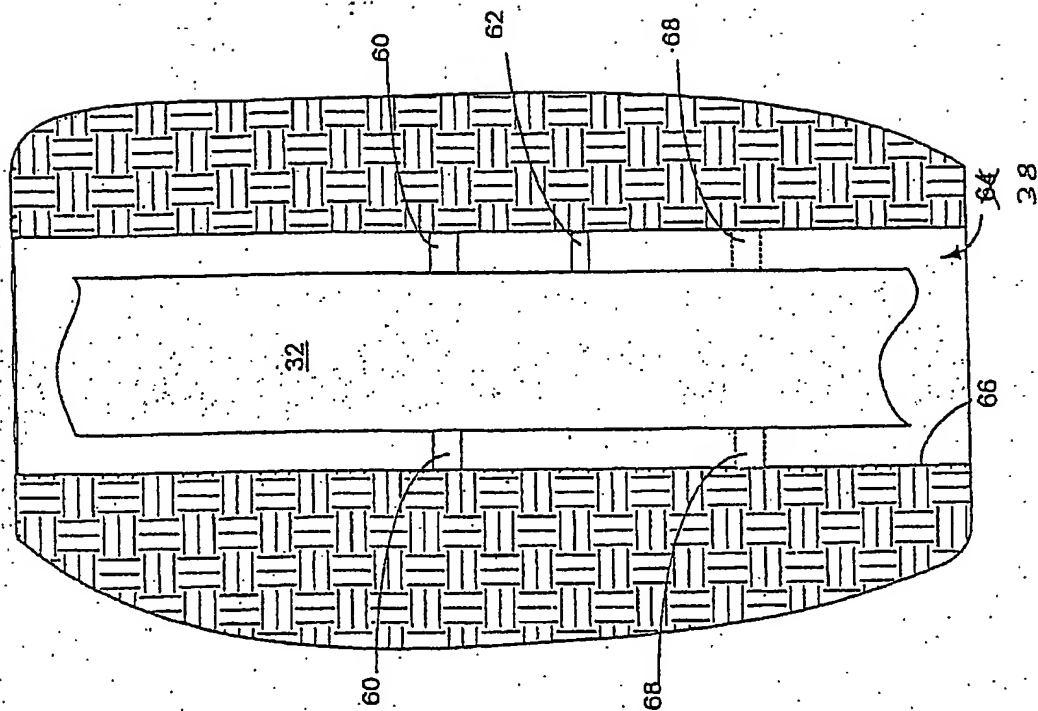


Fig. 2

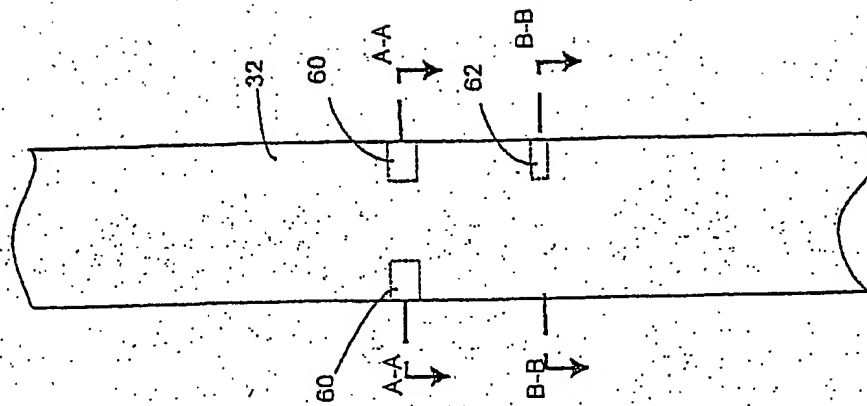


Fig. 3

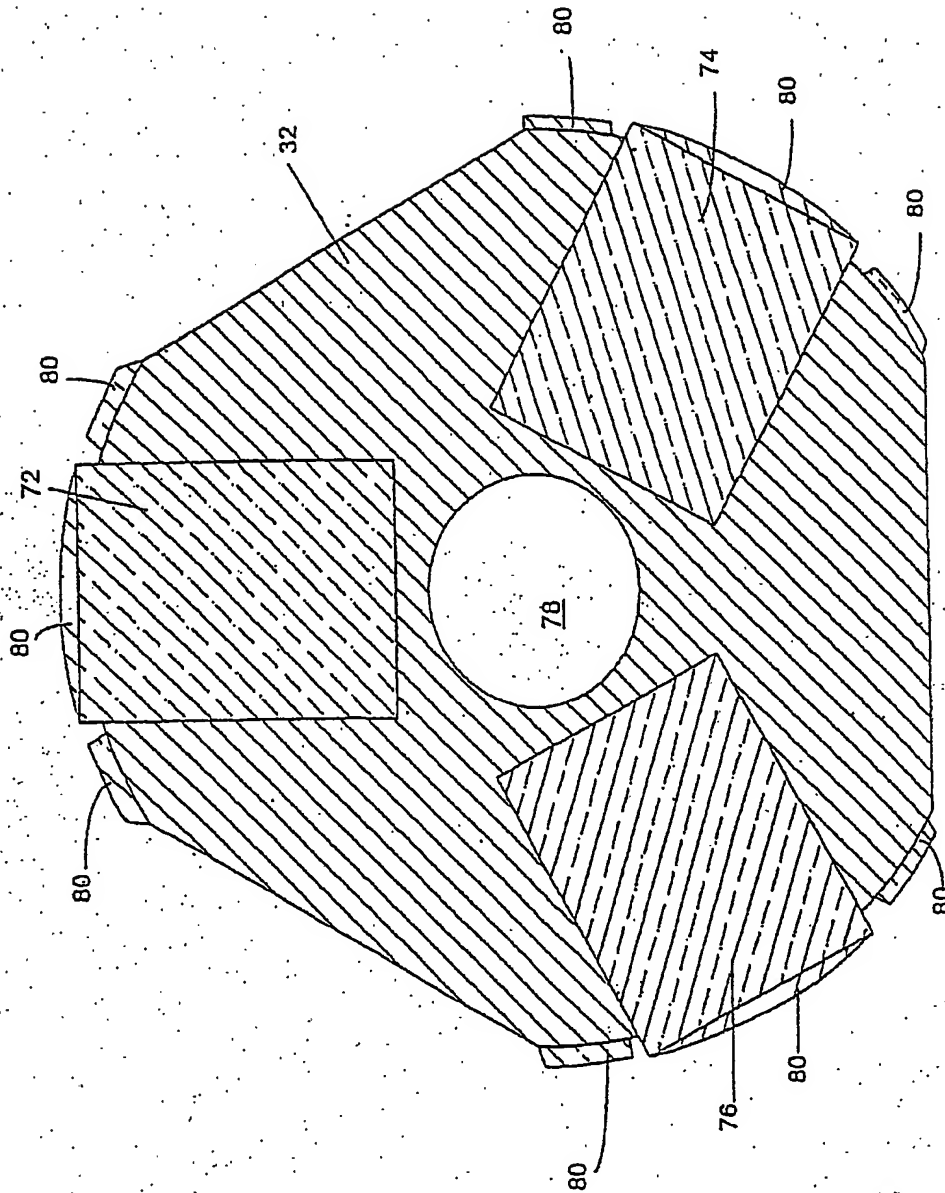


Fig. 4

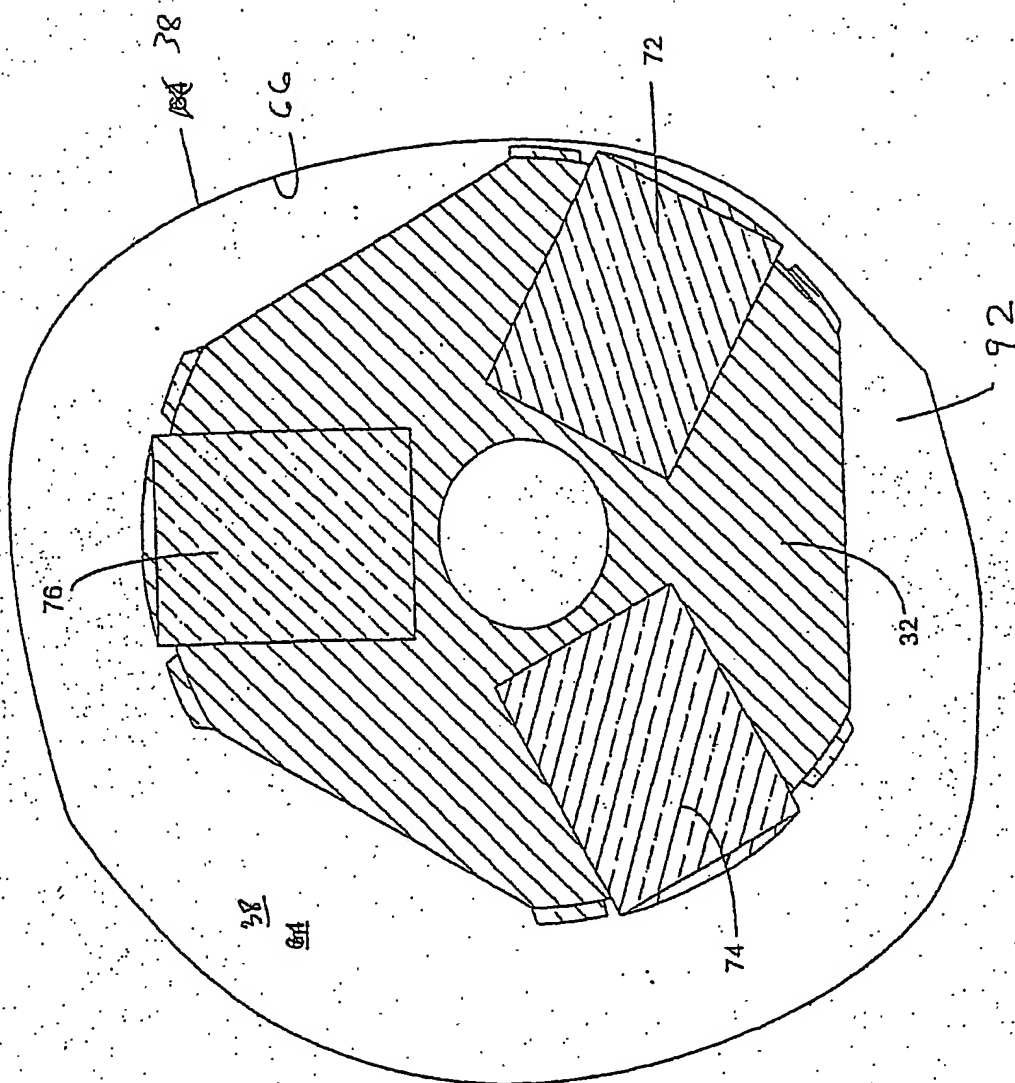


Fig. 5

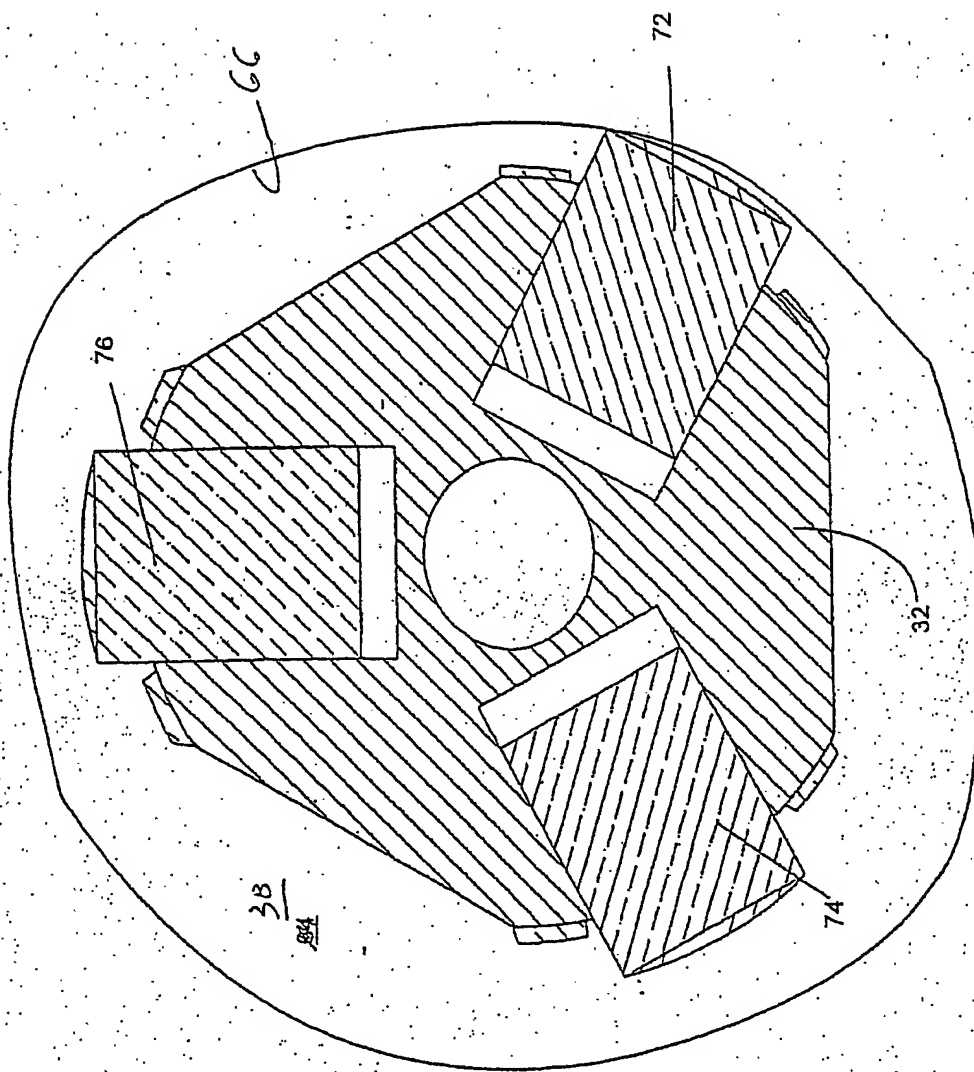


Fig. 6

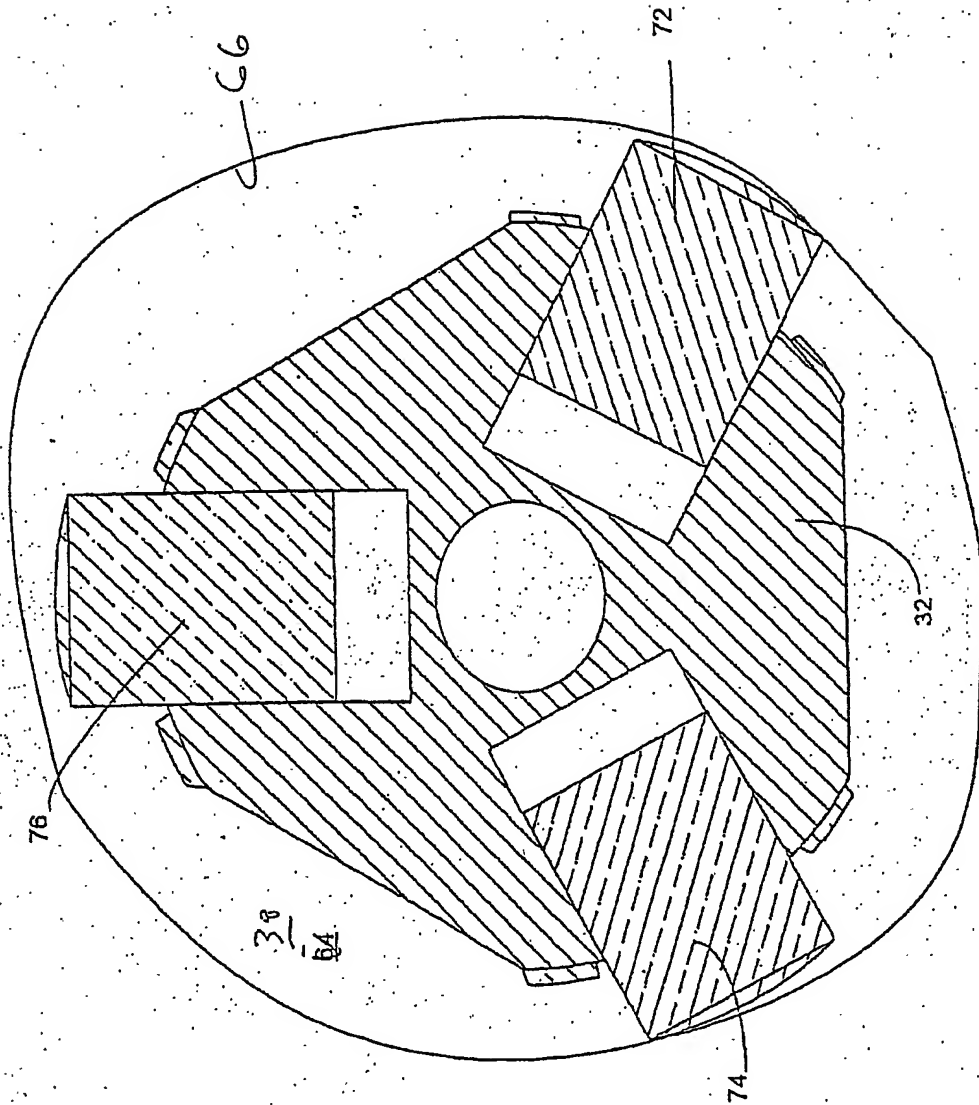


Fig. 7

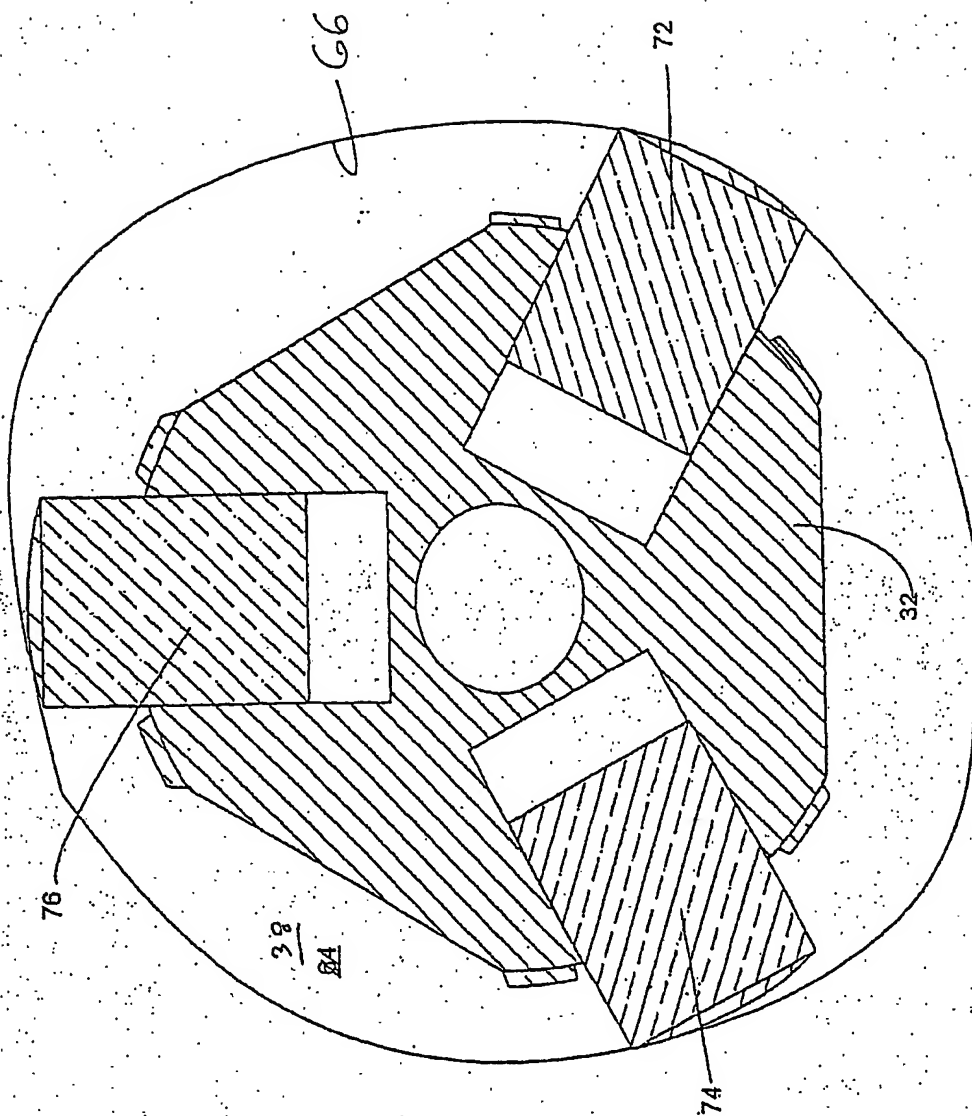


Fig. 8

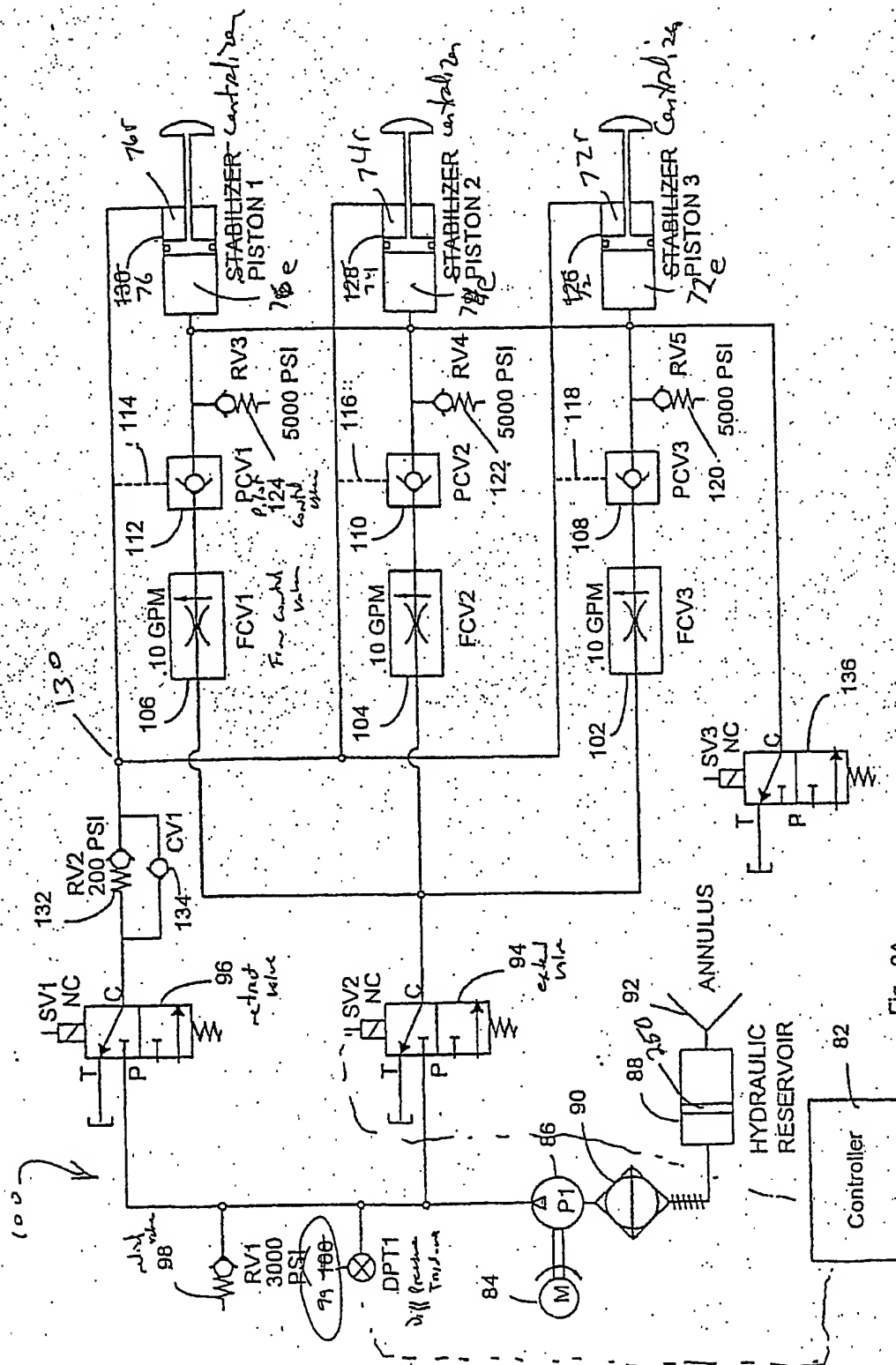


Fig. 9A

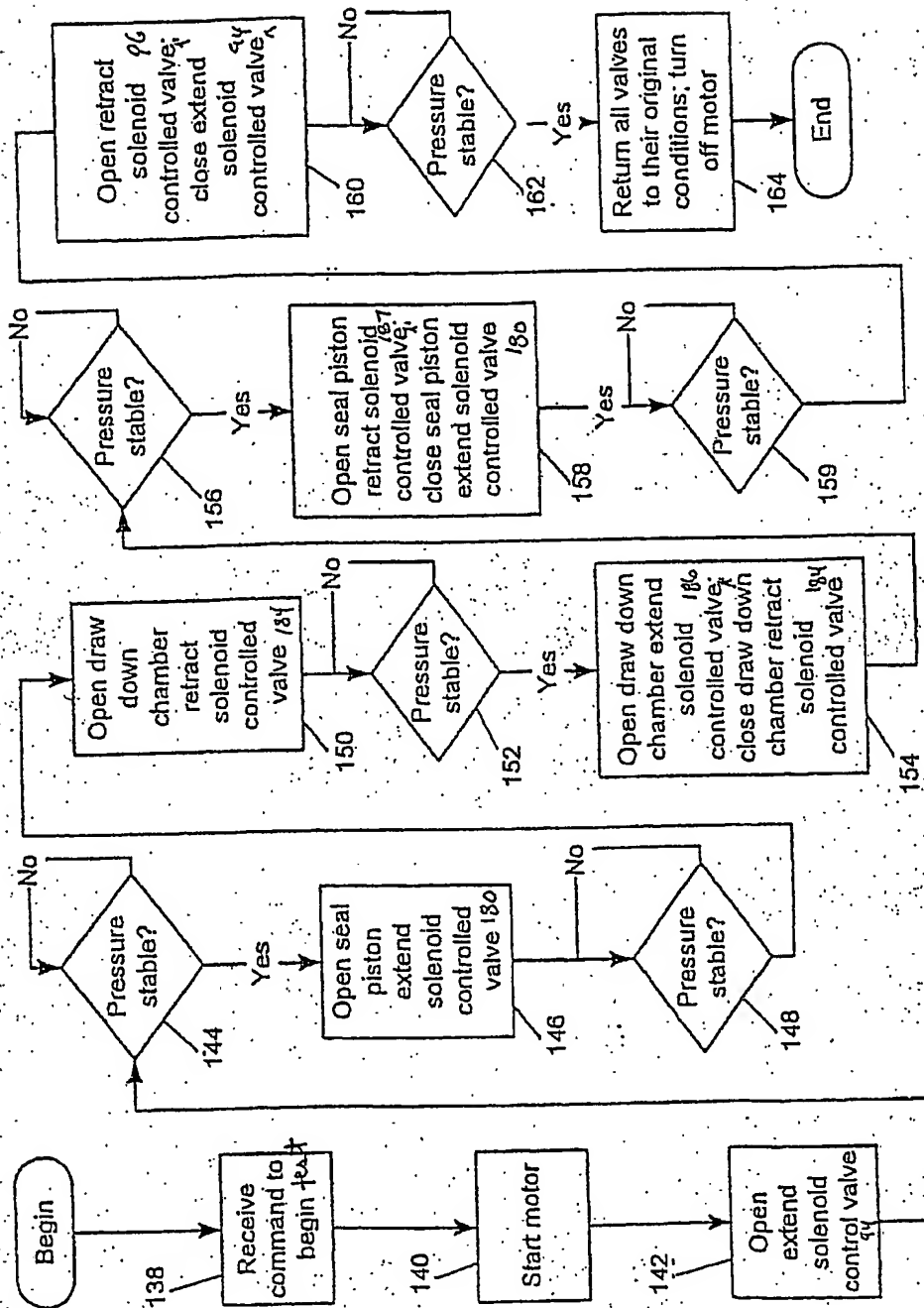


Fig. 9B

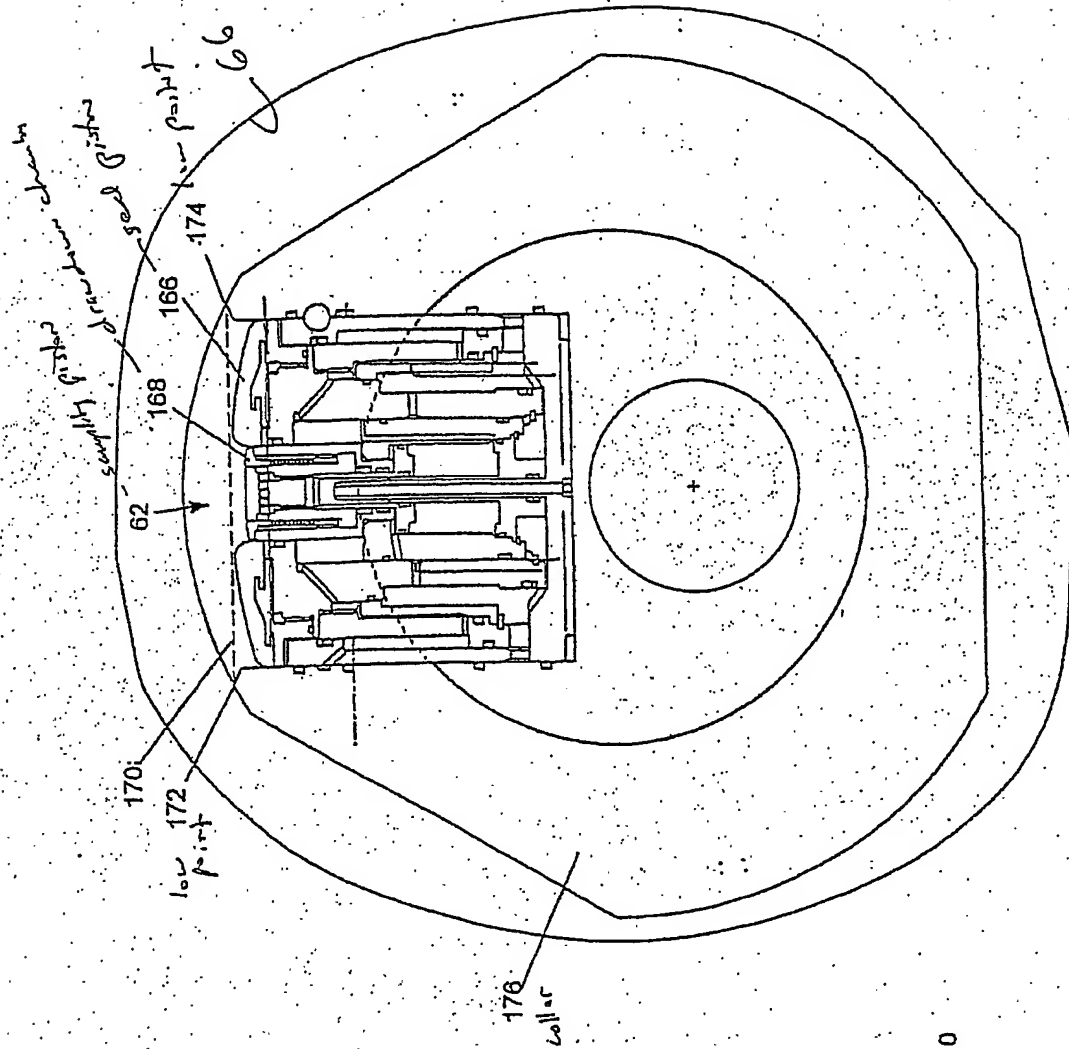


Fig. 10

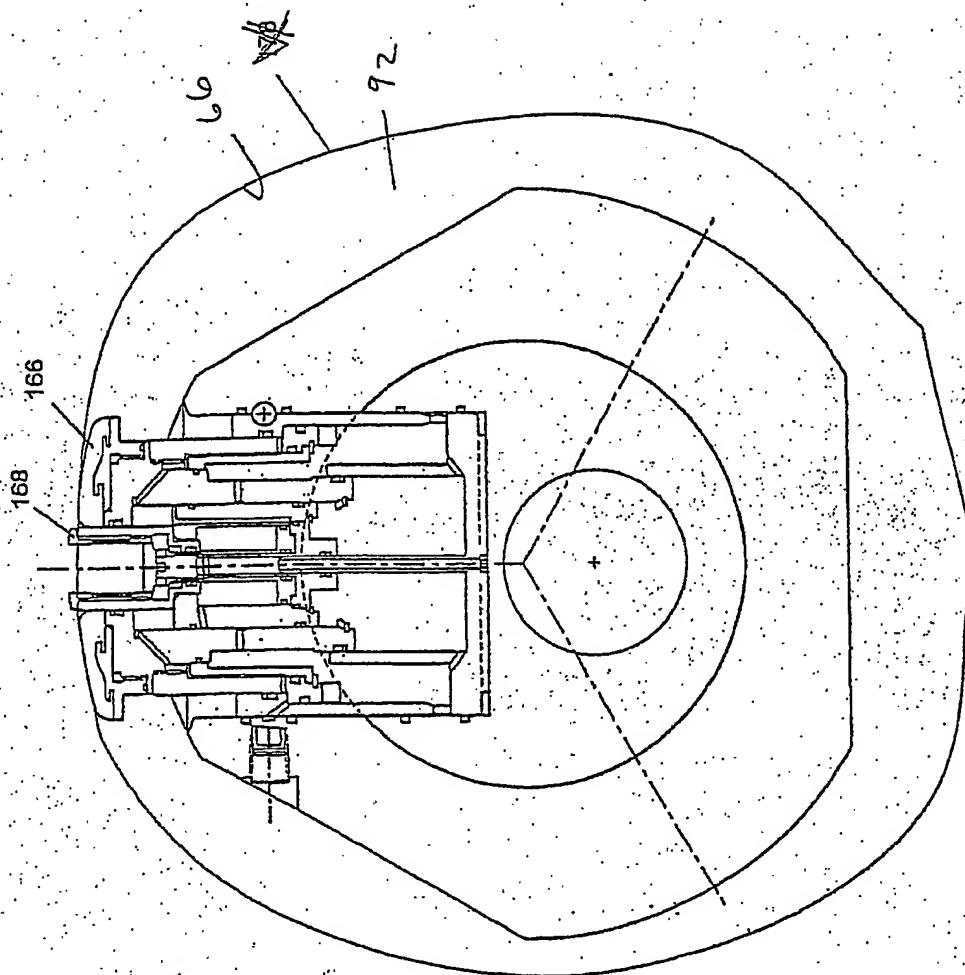
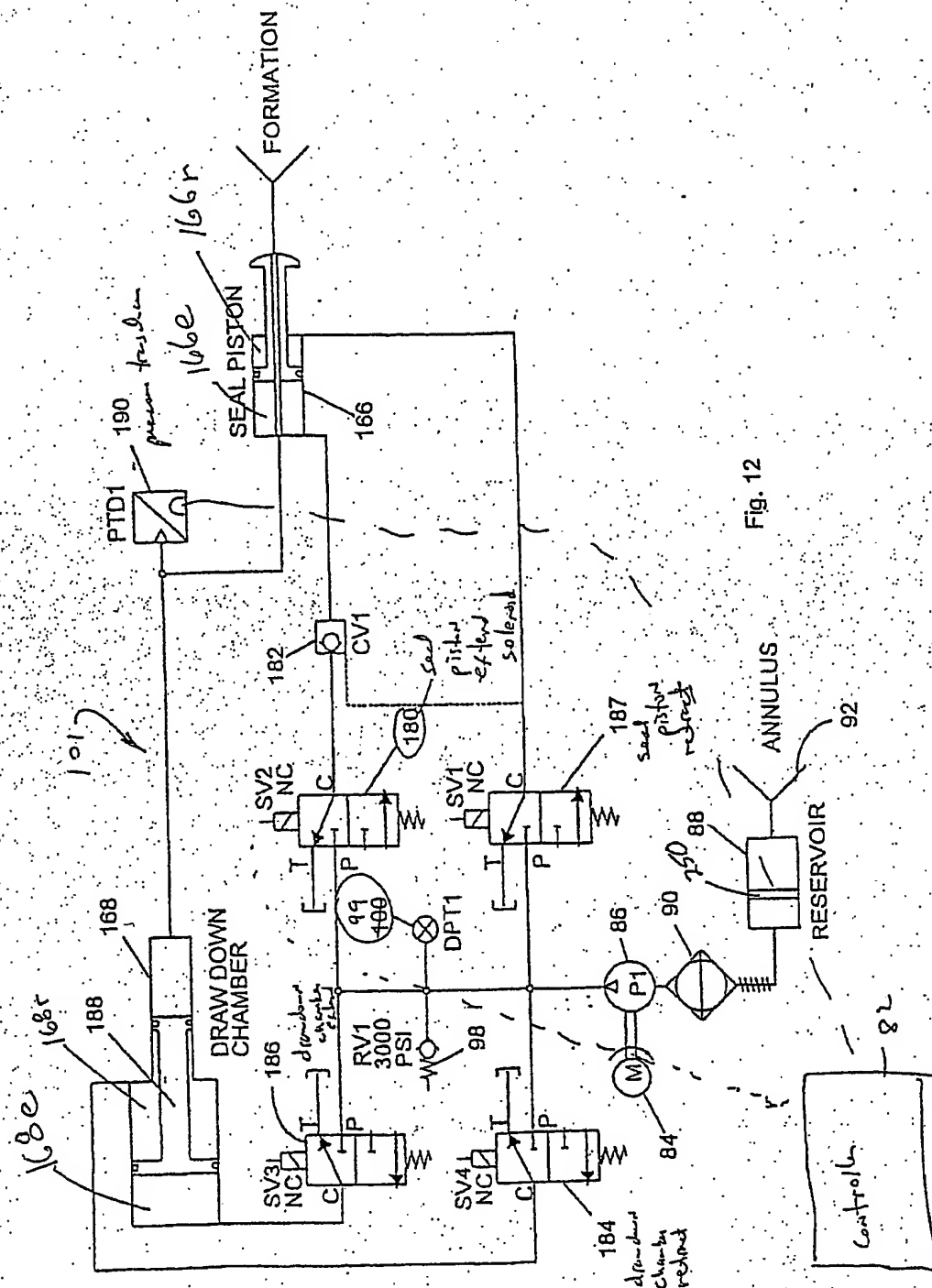


Fig. 11



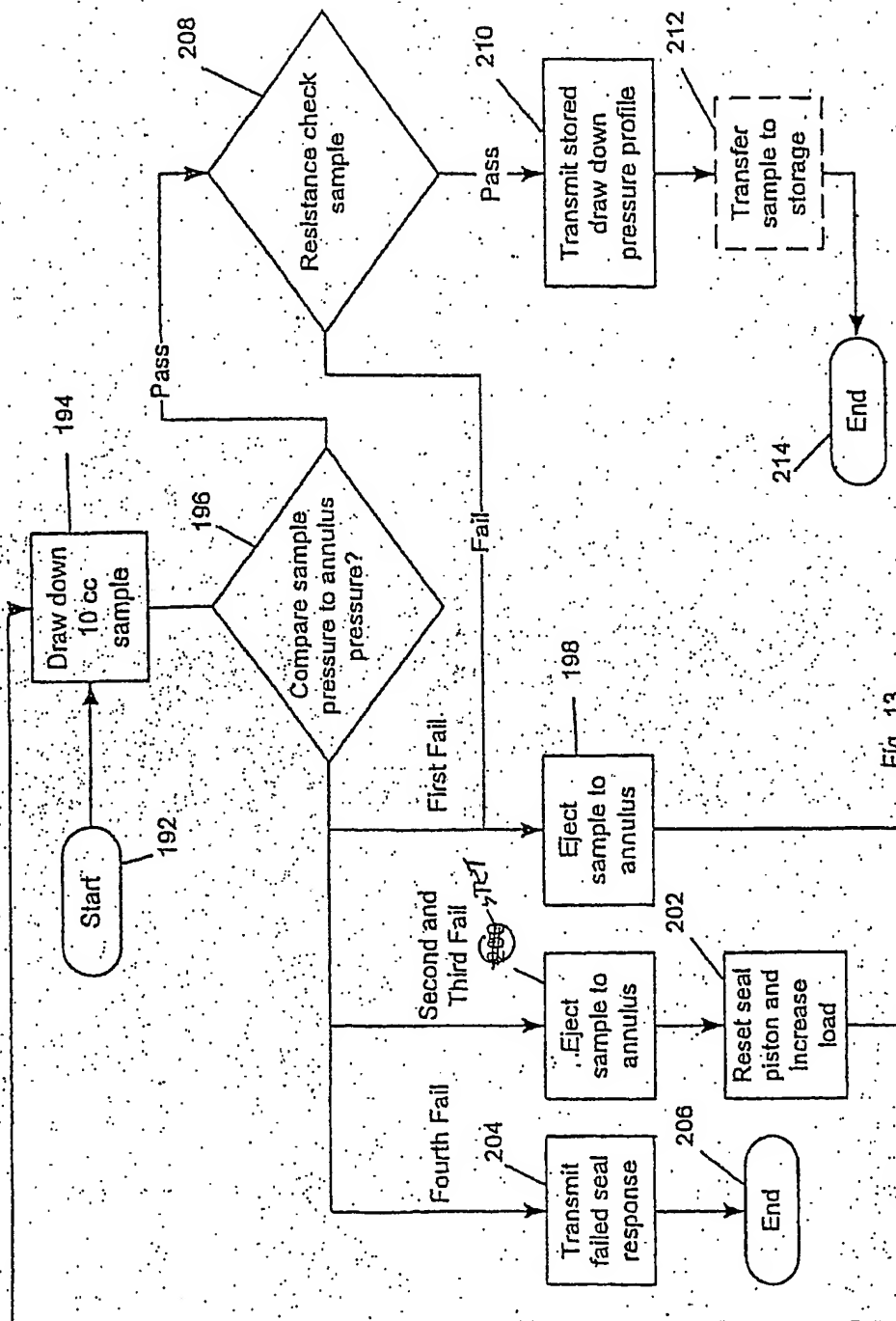


Fig. 13

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US03/15641

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G21B 1/00

US CL : 73/152.27

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 73/152.02, 152.03, 152.08, 152.23-152.28, 152.55, 152.54, 152.46; 166/264; 175/58, 59

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS EAST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 4,879,900 A (GILBERT) 14 November 1989 (14.11.1989), see entire document.	1,3-6,8,9,21,23-26 ----- 2
Y	US 4,860,580 A (DUROCHER) 29 August 1989 (29.08.1989), see Figure 3a.	2
X	US 6,164,126 A (CIGLENEC et al) 26 December 2000 (26.12.2000,) see Figures 3A and 3B.	7
A	US 4,593,560 A (PURFURST) 10 June 1986 (10.06.1986), see Figures 1 and 2.	1-29
A	US 5,644,076 A (PROETT et al) 01 July 1997 (01.07.1997), see Figure 2A.	1-29

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means	
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Date of the actual completion of the international search

10 AUGUST 2003

Date of mailing of the international search report

29 AUG 2003

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US03/15641

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,230,244 A (GILBERT) 27 July 1993 (27.07.1993), see Figure 1.	1-29

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